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Mineral Aspects of the Grace Mine Magnetite Deposit

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MINERAL ASPECTS OF THE GRACE MINE MAGNETITE DEPOSIT

by Akio Tsusue

ABSTRACT

A tabular magnetite ore deposit occurs in dolomite of Cambro-Ordovician age along the contact with Triassic diabase near Morgantown, Pa. From calcite-dolomite geothermometry and mineral paragenesis, it is inferred that calcite veins in dolomite were formed prior to the magnetite deposit at about 650°C, whereas the magnetite deposit was formed at less than about 500°C.

INTRODUCTION

Since the work of Spencer (1908), magnetite deposits of the Cornwall type in Pennsylvania have been considered to be contact metasomatic deposits by Callahan and Newhouse (1929), Hickok (1933), Hotz (1951), Gray and Lapham (1961), and Lapham (1962). The present paper describes the magnetite deposit of the Grace mine, Morgantown, Pennsylvania, and points out the low temperature character of the ore deposit.

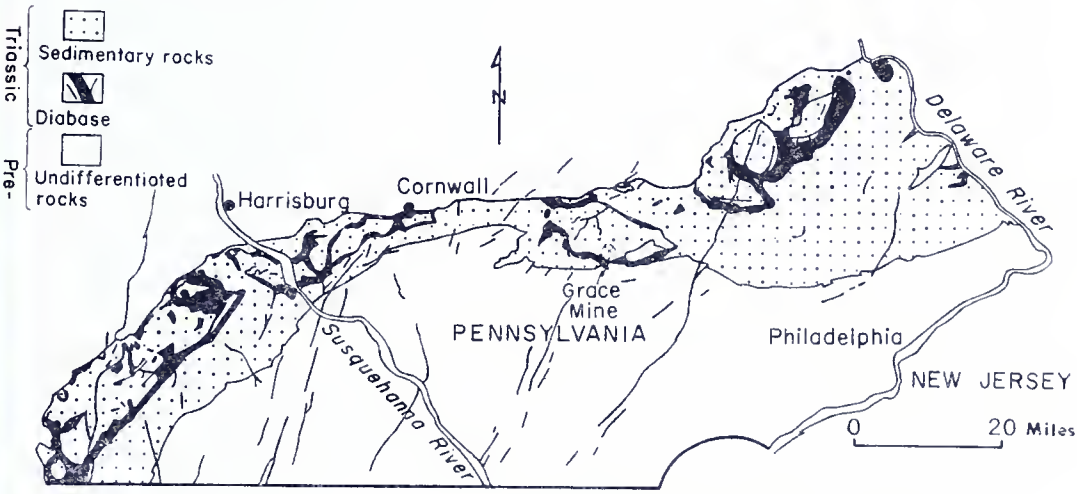

Figure 1. Map showing the distributian of diabase in Triassic rocks af southeastern Pennsylvania.

GEOLOGIC SETTING

Figure 1 shows the location of the Morgantown district. The areal geology of the district was described by Bascom and Stose (1938). As shown in Figure 2, the oldest rocks in the district are the Cambro-Ordovician dolomite and limestone which are closely folded and faulted. The Triassic sedimentary rocks unconformably overlie the

Modified from Boscom & Stose, 1938

Figure 2. Geologic map of Morgantown district, Pennsylvania.

Cambro-Ordovician rocks, are not folded, and dip generally northwestward. The Triassic Stockton Formation consists of a thick series of red sandstone and shale. These are intruded by large dikes and sills of diabase of Triassic age, which also invade the Paleozoic rocks.

As shown in Figure 3, the magnetite deposit of the Grace mine is found in dolomite of Cambro-Ordovician age along the upper contact of the diabase. The magnetite ore body occurs in a large tabular mass as much as 1500′ in length along strike and 390′ in thickness. The

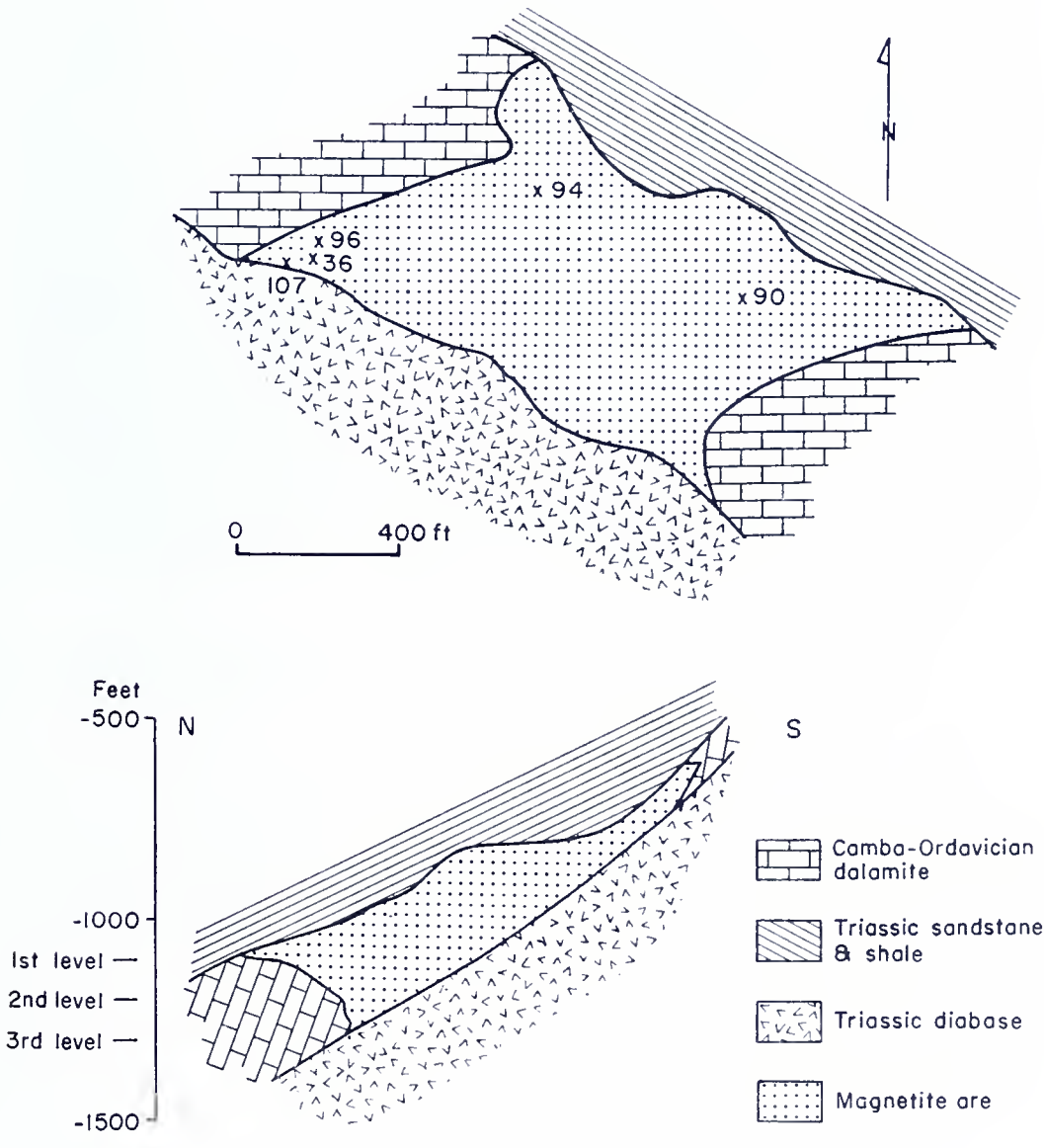

Figure 3. Geologic mop of Groce Mine 3rd level. Numbers refer to locotions shown in Table 2. Lower figure shows generolized north-south section through Grace Mine ore body.

strike of the deposit is N 65° W and the dip ranges from 20°-35° NE. In a few places the boundary between the deposit and diabase footwall is a fault with a strike of N 65°W and dip of 20°-35°NE. The hanging wall of the deposit is the Triassic red quartzitic sandstone and hornfels, probably a part of the Stockton Formation. Locally the Triassic rocks are separated from the deposit by dolomitic limestone. The northwestern and southeastern boundaries of the ore deposit are irregular, pinching out in these directions.

ORES AND SURROUNDING ROCKS

In this section a description of ores and surrounding rocks is given in succession from footwall to hanging wall.

Diabase.—The normal diabase is gray, medium-grained and uniform in texture. The main constituents are plagioclase, pyroxene, and what may best be designated as micropegmatite. Accessory minerals include iron ore minerals, amphibole, chlorite, apatite, biotite, and sphene. The grain size of the main constituents averages about 1 mm. The plagioclase is mostly fresh and normal zoning is common. Pyroxenes in the normal diabase are of three kinds: augite, pigeonite, and inverted pigeonite. Of the three, augite is the most abundant. Pigeonite is scanty; in thin sections its former position is indicated by finely striated patches intergrown with augite, a few with some clear uninverted pigeonite in them. The patches are now hypersthene containing microscopic lamellae of augite. The augite lamellae probably exsolved from pigeonite during cooling, and the pigeonite subsequently inverted to hypersthene. The so-called micropegmatite consists of graphic intergrowths of quartz and feldspar.

The diabase of the chilled contact can be divided into two facies on the basis of textural changes—the porphyritic and the non-porphyritic facies. The former occurs on the side toward the normal diabase, whereas the latter is on the side of the magnetite ore.

Throughout the porphyritic chilled contact zone the rock is holocrystalline. Its phenocrysts are plagioclase and olivine up to 0.5 mm in size. In the ground-mass colorless augite is intergrown with laths of plagioclase in typical diabasic texture. Olivine is frequently replaced by serpentine. The boundary between the porphyritic and non-porphyritic chilled contact facies is sharp.

Throughout the non-porphyritic chilled contact zone the rock is replaced by chlorite and sericite. The mineralogical composition of this zone was determined from X-ray spacing and intensity measurements of the specimen oriented to enhance the basal reflection, subjected to glycolation, and heated at 550°C. This zone is about 3 cm in width. The boundary between the non-porphyritic chilled contact facies and the magnetite ore is sharp.

Magnetite ore.—The magnetite ore can be divided into three types on the basis of paragenetic variations. These are 1) magnetite-serpentine ore, 2) magnetite-chlorite-serpentine ore, and 3) magnetite-phlogopite-serpentine ore. In many places small amounts of chalcopyrite, marcasite, pyrite, pyrrhotite, calcite, and dolomite are associated with these ore types.

The magnetite-serpentine ore consists of euhedral crystals of magnetite disseminated in the matrix of serpentine. At the somewhat similar deposit of Cornwall, Pa., Callahan and Newhouse (1927, p. 629-632, 1929, p. 408) reported two kinds of magnetite in the ore. They considered them to be magnetite and an oxidized form of magnetite. Hickok (1933, p. 218-223) also observed "brown" and "blue" magnetite, but was not able to determine the composition of these two kinds of magnetite. In the magnetite from the Grace mine that was examined, only one type of magnetite was seen having a unit cell $a_0 = 8.396$A.

The serpentine shows parallel extinction and has positive elongation. X-ray powder diffractometer patterns were made of the Grace mine serpentine (Table 1). The criteria used for the identification were those of Wittaker and Zussman (1956, p. 124). However, the writer was not able to determine which serpentine variety was present, because of a lack of critical peaks. DTA studies were also applied to the problem of identification. The curve for the Grace mine serpentine has a major endotherm at 715°C. as shown in Figure 4. If the criteria suggested by Faust and Fahey (1962, p. 77) are used, this serpentine consists of the undifferentiable pair of chrysotile and lizardite.

Table 1. *X-ray powder data of serpentine from Grace Mine.*

dA	I	2θ for $CuK_{\alpha 1}$
7.26	100	12.18
4.52	10	19.63
3.63	40	24.48
2.52	20	35.57
2.44	20	36.76
1.53	10	60.28

The magnetite-chlorite-serpentine ore is found only near the diabase, and consists of euhedral or subhedral grains of magnetite and lath-shaped chlorite crystals associated with fine-grained serpentine. The crystals of chlorite attain a length of 0.2 mm. The optical properties of this mineral are: β=1.592-1.596, optically positive, X=pale green, Y=

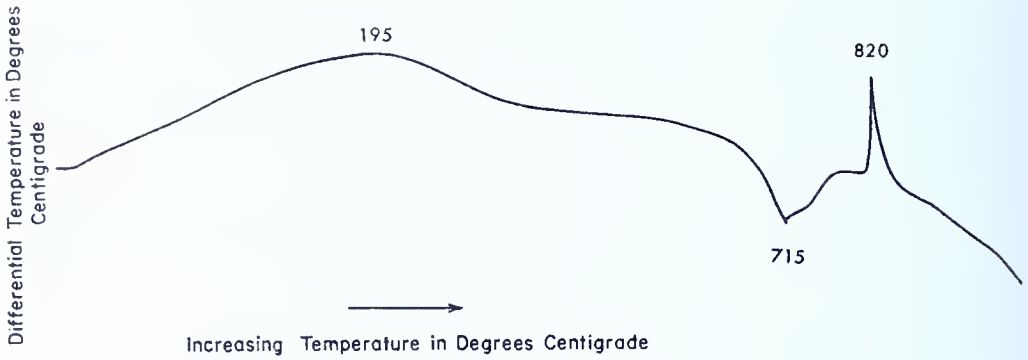

Figure 4. Differential thermal analysis curve of serpentine from Grace Mine.

pale green, Z=pale brown, very low birefringence, extinction almost parallel to the basal cleavage, and negative elongation. The basal spacing calculated from d(004) is 14.24 A.

The magnetite-phlogopite-serpentine ore is composed of euhedral grains of magnetite, short prismatic crystals of phlogopite, and fine-grained serpentine. The phlogopite prisms form an interwoven plexus with polygonal interstices filled with serpentine. The marginal part of some phlogopite grains is replaced by serpentine. The phlogopite crystals attain a length of 5 mm. The optical properties of the mineral are: optically negative, X=pale yellow, =pale greenish yellow, Z=pale greenish yellow, strong birefringence, and extinction almost parallel to the basal cleavage.

The common sulfide minerals in the magnetite ores are chalcopyrite, pyrite, pyrrhotite, and marcasite. Locally, extremely small amounts of sphalerite and galena are also present. The pyrrhotite and pyrite do not occur together.

The pyrite shows euhedral to subhedral outlines against the other sulfide minerals. It is isotropic and does not exhibit zonal structure. Subhedral grains of magnetite are included in it, suggesting that it was, at least, slightly later than the magnetite. Locally it is replaced by veinlets of chalcopyrite and sphalerite. The pyrrhotite shows strong anisotropism and polysynthetic twinning. Euhedral grains of magnetite are included in it, indicating its origin to be later than magnetite. The chalcopyrite exhibits mutual boundaries against the pyrrhotite. Small irregular masses of sphalerite are included in the chalcopyrite. Marcasite is found along fractures in the pyrrhotite.

Calcite and dolomite in the ores.—Both calcite and dolomite occur in the three kinds of magnetite ore. Special attention was given to these carbonates in the hope that their nature would shed light on the condi-

tions of ore formation. These two carbonates vary greatly in grain size, amount, and relative proportions from place to place. Calcite was identified by the staining methods suggested by Friedman (1959). Both dolomite and calcite locally form a matrix or fill the interstices between the grains of magnetite and other minerals. In such calcite no recognizable dolomite blebs are found. It was not possible to separate calcite from dolomite for X-ray analysis when these were present in the ore. However, the substitution of Mn and/or Fe in the calcite structure would produce a spacing change in the same direction as that produced by Mg. A study was therefore made assuming all variation in X-ray spacing to be due to Mg; under this assumption the Mg content of several calcite specimens coexisting with dolomite separated from the magnetite ores is listed in Table 2. Each (104) reflection was measured relative to the (111) reflection of standard silicon. The final 2θ (104) values tabulated are the average of five measurements which were obtained from pairs of reflections scanned from low to high angles. The Mg content in calcite was determined from d(104) by using the figure made by Goldsmith and Graf (1958, p. 97). It is estimated at about 1-2 molar per cent for all measurements.

Table 2. *Mg content of several calcites coexisting with dolomite in magnetite ore.*

Sample No.	2θ (104) for $CuK_{\alpha 1}$	d_A (104)	Mol % $MgCO_3$	Description
36	29.46	3.029	2	in magnetite-serpentine ore
90	29.46	3.029	2	ditto
94	29.43	3.032	1	ditto
96	29.46	3.029	2	ditto
107	29.43	3.032	1	in magnetite-phlogopite-serpentine ore

Calcite and dolomite outside the ores.—The dolomite adjacent to the ore deposit is white. It is granoblastic in texture, the grains having a maximum diameter of 0.1 mm. The other minerals in the dolomite include extremely small amounts of forsterite and clinopyroxene.

Calcite veins reaching 2 mm in width are found in fissures of dolomite adjacent to the deposit. The relation between the veins and the magnetite ore remains uncertain. Calcite, in grains up to 0.5 mm in diameter, everywhere includes dolomite blebs which are oriented at an angle to the trace of cleavage in the single crystal of calcite. From the subsolidus relation between $CaCO_3$ and $CaMg(CO_3)_2$ studied by Harker and Tuttle (1955) and Graf and Goldsmith (1955), a calcite

host is to be expected if the intergrowths are due to exsolution. The bulk chemical composition of the calcite vein is shown in Table 3. Extremely small amounts of Fe and Sr were detected in the analyzed specimen by the X-ray spectrograph. From Table 3 the Mg content in calcite before exsolution is estimated at about 9.4 molar per cent.

Table 3. *Chemical composition of calcite vein in dolomite.*

	Wt %	Mol ratios	Calcite	Remainder
SiO_2	0.66	11	—	11
Al_2O_3	0.68	7	—	7
FeO	0.18	3	3	
MgO	6.30	156	92	64
CaO	49.46	882	882	
CO_2	43.05	978	978	
SrO	0.11	1	1	
	100.44			

Mol % $MgCO_3$ in calcite before exsolution: 9.4
Analyst: H. Asari

CONSIDERATION OF THE TEMPERATURE OF FORMATION OF THE DEPOSIT

As known from the study of the system MgO-SiO_2-H_2O by Bowen and Tuttle (1949), the upper limit of the existence of serpentine is about 500°C in the presence of an excess of water. The main constituents of ores of the deposit are magnetite and serpentine. Therefore it is considered that the main part of the deposit was formed at a temperature less than about 500°C, if an excess of water was available during the formation of the deposit.

As described above, calcite crystals with oriented inclusions of very small dolomite blebs are found as veins in dolomite adjacent to the deposit. From the bulk chemical composition of the calcite vein and the subsolidus relations between $CaCO_3$ and $CaMg(CO_3)_2$ studied by Graf and Goldsmith (1958, p. 218-219), and Goldsmith and Heard (1961, p. 52-53), the temperature of formation of the veins is estimated to be about 650°C, if certain assumptions are made. These are 1) that calcite in the veins and dolomite adjacent to the veins coexisted in equilibrium and 2) that small concentrations of trace elements in solid solution do not significantly affect the equilibrium relations of the system $CaCO_3$-$MgCa(CO_3)_2$.

As mentioned before, calcite coexisting with dolomite is also found in the three kinds of magnetite ore. It has been observed that the amount of $MgCO_3$ in solid solution in the calcite of the magnetite ore is fairly constant in the ore deposit. It seems reasonable to assume that the Mg-rich calcite in the ore can be used to determine at least a minimum value of temperature of that ore, as indicated by the left limb of the solvus in the phase diagram for the system $CaCO_3$-$CaMg(CO_3)_2$ (Harker and Tuttle, 1955, p. 279, and Graf and Goldsmith, 1955, p. 118). From the data in Table 3 and the subsolidus relation revised by Goldsmith and Heard (1961, p. 53), it is thought that the minimum temperature of formation of calcite coexisting with dolomite in the magnetite ore was much less than 500°C, if certain assumptions are made. These are: 1) that all variations in X-ray spacing in calcite are due to Mg; 2) that calcite and dolomite coexisted in equilibrium; 3) that the equilibrium calcite composition has not changed significantly during the subsequent geologic events; and 4) that small concentrations of trace elements in solid solution do not significantly affect the equilibrium relations.

The effect of pressure on the solid solubility relations has been discussed by Goldsmith (1960, p. 109). The molar volume relations in the system $CaCO_3$-$CaMg(CO_3)_2$ would indicate that the pressure effect should be small.

From the data obtained it is inferred that the calcite veins in dolomite adjacent to the deposit were formed prior to the formation of the magnetite deposit at a temperature of about 650°C. The temperature of formation of the magnetite deposit is considered to be less than about 500°C. As described above, the weak endomorphic alteration of the diabase adjacent to the deposit also supports this conclusion.

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